Electrochemically Synthesized Conducting Polymer Nanocomposites for Energy Storage Devices

Final Synopsis submitted to fulfilment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

In

PHYSICS

Submitted By

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Final - Synopsis

Conducting polymer nanocomposite have attractive material with unique characteristics are suitable for various potential applications such as solid state batteries, sensors, solar energy, photovoltaic device, supercapacitor, electromagnetic interference shielding, and light emitting diode (LED) [1-5]. PANI nanocomposite is one of the most intensively investigated due to its easily synthesis, environmental stability, relatively high electrical conductivity, and high surface to volume ratios, low cost and simplistic method [6-10]. Presently PANI is very good recognised conjugate polymers among the conducting polymers [11], because of its desirable physical properties are exactly suitable for energy storage, and energy conversion devices applications [12]. But, there are few disadvantages like solubility, chemical swelling, shrink, and weak mechanical properties of PANI would limit to use in the various practical applications. To overcome these problems the researchers have been followed different synthesis techniques such as in-situ, electrospining, electrochemical and irradiation as well as different monomer concentration, catalysts, composite, nanocomposite and surfactant are used to improve the material properties [13]. The electrochemical deposition is an accurate and quality product because of the deposition process takes place as per the electrostatics, in which the sample deposits on anode electrode by attracting opposite charges. This method produced the chemistry stable material may prevent the chemical swelling and shrink whenever charges diffuse between electrode-electrolyte-electrode during the cyclic process [14]. The CuO nano particles is frequently used in many applications because of its high electrical conductivity and small band gaps with optimised morphology or grain size, structural phase, and optical properties [15]. The super capacitor behaviour of polyaniline/CuO, polypyrrole/CuO, and PEDOT/CuO nanocomposite, was synthesized using in-situ reaction reported 2000 cycles with 286 F/g [16-

19]. On the basis of energy storage mechanism, supercapacitor is classified into pseudocapacitor and electrical double-layer capacitor [20]. From the literature review it is seen that the polyaniline-graphene oxide composite was observed 2000 cycles with 475 F/g [1], the electro-oxidation of phenol to benzoquinone/hydroquinone on PANI reported 2000 cycles with 424 F/g [21]. In the present case PANI/CuO nanocomposite (PCN) synthesized using electrochemical deposition method and achieved a long cyclic stability 4000 cycles with specific capacitance value is 294F/g, it is first time unusual long maximum cyclic stability with capacitance was observed as compared to reported. The electrochemically synthesized PANI-nickel oxide hybrid electrode is 2000 cycles with 263 F/g reported [22], and the mixed ion-electron conducting polymer PEDOT: PSS and sulfonated lignin has reported 700 cycles with 230 F/g [23]. This paper reports the investigation of CV and GCD cyclic performance of electrochemically synthesized PCN nanocomposite and characterized their chemical interaction, structural phase, morphology, and thermal properties. The CV study exhibit a rectangular CV curve which is a characteristic of supercapacitor and the GCD enhanced the cyclic stability along with this C_{sp} value of both CV and GCD increases as increasing nano concentration. Hence, PANI/CuO nanocomposite sample electrode can be used in the long durability energy storage devices such as supercapacitor and other potential applications [24].

The supercapacitors are classified into three classes;

1. Electrical double layer capacitor (EDLC).
2. Pseudocapacitors.
3. Hybrid capacitors

These are characterized by its unique mechanism of charge storage. EDLC stores the charge electrostatically or non-faradaically, i.e. charges accumulate on the surface of the electrode. In

this process, charge separation takes place between the electrode and the electrolyte interface. Usually, carbon-based materials such as activated carbon, graphene, carbon nanotube, conjugated polymer were used in EDLCs. In pseudocapacitor, the charge storage happens faradaically, and the transfer of charges takes place between electrode and electrolyte. This Faradic mechanism might allow pseudocapacitors to attain maximum capacitance and energy density than that of EDLC. The polyaniline metal oxide nano composites show excellent electrical conductivity, specific capacitance and charging/discharging process for super capacitor applications [25].

Aims and objective of the present study

The present study focused on the battery, super capacitors and energy storage device applications of conducting polymer nanocomposites with different metal oxides. The main aimof this work is to study the modifications in the conducting polymer nanocomposites for energy storage device applications. Aims and objectives of this research work is proposed as follows,

The present work entitled “Electrochemically synthesized conducting polymer nanocomposites for energy storage devices” consists of theoretical background, analytical studies, results and discussion with below specified objectives.

- ☑ The study of conducting polymer/metal oxide nanocomposites prepared by electrochemical synthesis method for energy storage devices.
- ☑ To know the chemical interaction, structural phase, thermal stability, surface morphology and particle size of the compound. The conducting polymer and different metal oxide nanocomposites are characterized by Fourier transform infrared spectroscopy (FTIR), X-ray diffraction (XRD), Differential scanning calorimeter (DSC), Field emission scanning electron microscope (FESEM). Transmittance electron microscope (TEM).

- ☑ Fabrication of working electrode using PANI nanocomposites on stainless steel (SS 304) by doctor blade method to study the CV and GCD techniques for cyclic stability.
- ☑ The cyclic voltammetry (CV), galvanostatic charging discharging (GCD) and electrochemical impedance spectroscopy (EIS) of the polymer NCs are studied by using CHI-660Eelectrochemical workstation.

The polymer nanocomposites have been synthesized by the electrochemical deposition method and different concentration were prepared. After synthesis the characterizations was carried out according to the aims and objects as proposed and finally achieved or reached the expectations of the proposed work.

Novelty of Work

The novelty of present work is the specific capacitance value 424 F/g and galvanostatic charging-discharging cyclic stability up to 4000 cycles. This result suggests that the polyaniline/metal oxide nanocomposites play an important role in enhanced long durable cyclic stability in supercapacitor electrode and energy storage device applications.This electrochemical method gives accurate and which may prevent chemical hazards like swelling and shrinkage during the diffusion mechanism. In this method, electrical energy has been converted into chemical energy and vice versa, this mainly depends on the electrode material selected. Therefore, the selection of appropriate electrode material is important to improve the properties of the supercapacitor electrode.

It is proposed to divide the thesis into six chapters. The chapter wise outline of the thesis is presented as introduction, materials and methods, three working chapters and conclusions and scope for future work.

Chapter - 1: Introduction

This chapter summarise the basics and their classification with physical properties of conducting polymers as well as various metal nanocomposites. The electrochemical synthesis method is a most significant one in which reaction occurs between electrode and electrolytes (sample). The features of electrochemically synthesized on physical and chemical properties of polymer nanocomposites are explained. It is also explained that electrochemically deposited polymer nanocomposite for supercapacitor application and the mechanism involved in the charge storage process. Literature review on physical properties of electrochemically synthesized polymer nanocomposites for energy storage devices. The motivation behind this work with aims and objective was elaborated in details.

Chapter - 2: Materials and Experimental Methods

Chapter covers the details about used aniline monomer, and other chemicals such as copper oxide nano particles and different metal oxides, 1-Methyl-2-pyrrolidone (NMP) used as a solvent and stainless steel electrode for electrochemical studies. The electrode fabrication of polymer nanocomposite on stainless steel using doctor blade technique and examined electrochemical performance for energy storage devices using three electrode systems. The characterization and experimental techniques have been employed to study the physical properties of polymer nano composite.

Chapter - 3: Study of Structure Morphology Thermal and Electrochemical Performance of Electrochemically Synthesized Polyaniline/Copper Oxide Nanocomposite for Energy Storage Devices

This chapter presents the polyaniline/copper oxide nanocomposite optical properties, thermal, morphological, dielectric and electrical conductivity properties. Optical and thermal studies were

carried out using the UV-Visible spectroscopy and thermal techniques (TGA, DTA and DSC) analysis respectively. The morphology study carried out using Field emission scanning electronic microscopy analysis (FESEM). The structural and chemical characterizations were studied using Fourier transform infrared spectroscopy (FTIR) and X-ray diffractometer (XRD) techniques respectively. This chapter reports the investigation of CV and GCD cyclic performance of electrochemically synthesized PCN nanocomposite and characterized their chemical interaction, structural phase, morphology and thermal properties. The CV study exhibit a rectangular CV curve which is characteristic of supercapacitor and the GCD enhanced the cyclic stability is 4000 cycles and specific capacitance (C_{sp}) value is 294 F/g with increasing nano concentration.

Chapter - 4: Cyclic Voltammetry, AC Conductivity, Morphology and Optical Study of Electrochemically Synthesized PANI/ZnO Nanocomposites

This chapter describes the polyaniline zinc oxide nanocomposite synthesized by electrochemical deposition method. The change in the structure, morphology, dielectric constant and AC conductivity with zinc oxide concentration were studied. The XRD shows formation of the more amorphous area helps to easy flow of ions. The FT-IR result confirms chemical interaction between polyaniline and nanocomposites. The FESEM images show the surface morphology changes with increasing zinc oxide nanocomposites. The dielectric real (ε′) and imaginary (ε″) parameters are suddenly decreased in a low frequency region, subsequently independent at higher frequency region. The AC conductivity shows increases with frequency and temperature for all samples. The dielectric permittivity and frequency dependent conductivity were found to increase with increasing nanocomposites. The dielectric parameters and conductivities of the polymer nanocomposites were enhanced after addition of concentrations. The good cyclic

voltammetry of electrochemical performance was observed at different scan rates from 100 - 500 mV/s.

Chapter - 5: Study of Electrochemical Performance and Electrical Conductivity of Electrochemically Synthesized PANI/Co_3O_4 Nanocomposites

Electrochemically synthesized polyaniline cobalt oxide nanocomposite and studied the electrochemical properties for energy storage devices. Polyaniline cobalt oxide nanocomposites were characterized by various techniques and observed the changes using FT-IR, XRD, FESEM, UV-Visible absorption, Optical band gaps, Dielectric constant, loss, AC conductivity and electrochemical measurement. The FT-IR analysis confirmed that the chemical composition and the surface morphology observed changes with increasing nanocomposite by FESEM. The structural phase of the sample was noticed using XRD techniques. Optical absorption and band gap studies revealed that band gap found decreases with increasing the nano concentration. Dielectric parameters, electrical conductivity and electrochemical stability of PCO nanocomposite are studied, which can be changed or improved by changing the different nano concentrations. The AC conductivity of polyaniline cobalt oxide nanocomposites is increased at higher concentration was noticed. The electrochemical performance of cyclic voltammetry was observed within the potential window range between -4 volt to +4 volt at different scan rates from 100 - 500 mV/s. The observed results clearly noticed that the PCO nanocomposite material may useful in the rechargeable batteries, supercapacitors and energy storage devices.

Chapter - 6: Summary and Conclusions

The successfully the PANI/CuO nanocomposites, PANI/ZnO nanocomposites, and PANI/Co_3O_4 nanocomposites are prepared by using electrochemical synthesis method. The PANI nanocomposites were characterized using different techniques to study the influence of nano

concentration in the PANI matrix. The structural properties were changed by the variations in the chemical bonds; the surface morphology has changed from grain to rod like structure. The amorphousity is increased due to the nano concentration increases in polyaniline and hence increased the thermal stability. The optical absorption was increased by shifting the wavelength towards higher end (red shift) as a results decrease in the optical band gaps was noticed. The electrical conductivity was increased in decimals (10^{-6} to 10^{-4} S/cm), the properties significantly increased with increase in the nano concentration. The electrochemical performance of CV and GCD confirms high cyclic stability achieved about 4000 cycles and the specific capacitance value is 294 F/g. From the obtained results, it is clear that, due the polyaniline nanocomposites the physiochemical properties were modified and hence the improvements in the cyclic stability and specific capacitance. The future scope of work will done by selecting the good electrode materials and electrolytes as well as optimising fabrication of electrode in confined environment to improve the electrochemical properties of the polymer nanocomposites for desired applications in the field of supercapacitor and energy storage device applications.

References

1. Wang WD, Lin XQ, Zhao HB, Lu QF (2016) Nitrogen-doped graphene prepared by pyrolysis of graphene oxide/polyaniline composites as supercapacitor electrodes. *J Anal Appl Pyrolysis* **120:**27-36
2. Liang J, Su S, Fang X, Wang D, Xu S (2016) Electrospun fibrous electrodes with tunable microstructure made of polyaniline/multi-walled carbon nanotube suspension for all-solid-state supercapacitors. *Mater SciEng B***211**:61-66
3. Obaid AY, El-Mossalamy EH, Al-Thabaiti SA, El-Hallag IS, Hermas AA, Asiri AM (2014) Electrodeposition and characterization of polyaniline on stainless steel surface via cyclic, convolutive voltammetry and SEM in aqueous acidic solutions. *Int J ElectrochemSci* **9**:1003-1015
4. Hui N, Chai F, Lin P, Song Z, Sun X, Li Y, Luo X (2016) Electrodeposited conducting polyaniline nanowire arrays aligned on carbon nanotubes network for high performance supercapacitors and sensors. *ElectrochimActa* **199**:234-241
5. Sankar KV, Selvan RK (2016) Fabrication of flexible fibersupercapacitor using covalently grafted $CoFe_2O_4$/reduced graphene oxide/polyaniline and its electrochemical performances. *ElectrochimActa* **213**:469-481
6. Chang TW, Lin LY, Peng PW, Zhang YX, Huang YY (2018) Enhanced electrocapacitive performance for the supercapacitor with tube-like polyaniline and graphene oxide composites. *ElectrochimActa* **259:**348-354
7. Patil AM, Lokhande AC, Shinde PA, Lokhande CD (2018) Flexible Asymmetric Solid-State Supercapacitors by Highly Efficient 3D Nanostructured α-MnO_2 and h-CuS Electrodes. *ACS Appl Mater Interfaces* **10(19):**16636-16649
8. Qiu H, Han X, Qiu F, Yang (2016) Facile route to covalently-jointed graphene/polyaniline composite and its enhanced electrochemical performances for supercapacitors. *Appl Surf Sci* **376**:261-268
9. Song XL, Guo JX, Guo MX, Jia DZ, Sun Z, Wang LX (2016) Freestanding needle-like polyaniline–coal based carbon nanofibers composites for flexible supercapacitor. *ElectrochimActa* **206**, 337-345

10. Luo J, Zhong W, Zou Y, Xiong C, Yang W (2016) Preparation of morphology-controllable polyaniline and polyaniline/graphene hydrogels for high performance binder-free supercapacitor electrodes. *J Power Sources* **319**:73-81
11. Patil DS, Pawar SA, Kim JH, Patil PS, Shin JC (2016) Facile preparation and enhanced capacitance of the Ag-PEDOT: PSS/polyanilinenanofiber network for supercapacitors. *ElectrochimActa* **213:**680-690
12. Kim KM, Lee YG, Shin DO, Ko JM (2016) Supercapacitive properties of layered electrodes composed of electrodeposited RuO_2 and polyaniline. *Electrochim*Acta **196,**309-315
13. Ramkumar B, Yuvaraj S, Surendran S, Pandi K, Ramasamy HV, Lee YS, Selvan RK (2018) Synthesis and characterization of carbon coated $LiCo_1/3Ni_1/3Mn1/3O_2$ and bio-mass derived graphene like porous carbon electrodes for aqueous Li-ion hybrid supercapacitor. *J PhysChem Solids***112**:270-279
14. Zhao C, Ren F, Cao Y, Xue X, Duan X, Wang H, Chang L (2018) Facile synthesis of $Co(OH)_2/Al(OH)_3$ nanosheets with improved electrochemical properties for asymmetric supercapacitor. *J PhysChem Solids***112:**54-60
15. Ramphal IA, Hagerman ME (2015) Water-processablelaponite/polyaniline/grapheme oxide nanocomposites for energy applications. *Langmuir* **31(4):**1505-1515
16. Ates M, Serin MA, Ekmen I, Ertas YN (2015) Supercapacitor behaviours of polyaniline/CuO, polypyrrole/CuO and PEDOT/CuOnanocomposites. *Polym Bull* **72(10):** 573-2589
17. Usman M, Pan L, Asif M, Mahmood Z, Khan MA, Fu X (2016) Enhanced electrochemical supercapacitor properties with synergistic effect of polyanilinegraphene and AgxO. *Appl Surf Sci* **370:**297-305
18. Thines KR, Abdullah EC, Ruthiraan M, Mubarak NM, Tripathi M (2016) A new route of magnetic biochar based polyaniline composites for supercapacitor electrode materials. *J Anal Appl Pyrolysis***121**:240-257
19. Anbalagan AC, Sawant SN (2016) Brine solution-driven synthesis of porous polyaniline or supercapacitor electrode application. *Polymer* **87:**129-137

20. Chang WM, Wang CC, Chen CY (2016) Plasma-induced polyaniline grafted on carbon nanotube-embedded carbon nanofibers for high-performance supercapacitors. *ElectrochimActa* **212**:130-140
21. Han C, Ye Y, Wang G, Hong W, Feng C (2018) Selective electro-oxidation of phenol to benzoquinone/hydroquinone on polyaniline enhances capacitance and cycling stability of polyaniline electrodes. *ChemEng J* **347:**648-659
22. Navale YH, Navale ST, Dhole IA, Stadler FJ, Patil VB (2018) Specific capacitance, energy and power density coherence in electrochemically synthesized polyaniline-nickel oxide hybrid electrode. *Org Electron* **57:**110-117
23. Edberg J, Inganas O, Engquist I, Berggren M (2018) Boosting the capacity of all-organic paper supercapacitors using wood derivatives. *J Mater Chem A* **6(1):**145-152
24. S.P. Ashokkumar, H. Vijeth, L. Yesappa, M. Niranjana, M. Vandana & H. Devendrappa, Inorg. Chem. Commun, 115 (2020) 107865.
25. S.P. Ashokkumar, L. Yesappa, H. Vijeth, M. Niranjana, M. Vandana & H. Devendrappa Materials Research Express, 6(12) (2020). 125557.

Paper Published in Journals and Conference Proceedings

1. A Paper entitled "Electrochemically Synthesized Polyaniline/Copper Oxide Nano composite: To Study Optical band gap and Electrochemical performance for Energy Storage Devices" in ***Inorganic Chemistry Communications***.
Ashokkumar S P, Vijeth H, Yesappa L, Niranjana M, Vandana M, Devendrappa H*
https://doi.org/10.1016/j.inoche.2020.107865

2. A paper entitled "Structure, Morphology, Thermal and Electrochemical Studies of Electrochemically Synthesized Polyaniline/Copper Oxide Nanocomposite for Energy Storage Devices". In ***Material Research Express (MRX).***
Ashokkumar S P, Yesappa L, Vijeth H, Niranjana M, Vandana M, Devendrappa H*
https://doi.org/10.1088/2053-1591/ab5dde

3. A paper entitled "Electrochemically Synthesized and Characterization of the Conducting Polyaniline/Zinc Oxide Nanocomposites for Energy Storage Device Applications". In ***Journal of Materials Science: Materials in Electronics (JMSE)***.
Ashokkumar S P, Vijeth H, Vandana M, H. Devendrappa*
Communicated, Submission ID: JMSE-D-20-02787

4. A Paper entitled "Surface morphology and electrochemical studies on polyaniline/CuO nanocomposites" **AIP Conference Proceedings,** 1953, 030095 (2018).
Ashokkumar S P, Vijeth H, Yesappa L, Niranjana M, Vandana M, Basappa M and Devendrappa H* https://doi.org/10.1063/1.5032430

5. A Paper entitled "Electrical conductivity and morphology of electrochemical synthesized polyaniline/CuO nanocomposites" **AIP Conference Proceedings,** 1953, 030222 (2018).
Ashokkumar S P, Yesappa, L., Vijeth, H., Niranjana, M., &Devendrappa, H.
https://doi.org/10.1063/1.5032557

6. A paper entitled "Lower optical band gap and morphology of electrochemically synthesized polyaniline/CuO nanocomposites" **AIP Conference Proceedings,** 2115, 030059 (2019).
Ashokkumar S P, Vijeth H, Yesappa L, Vandana M, Devendrappa H*
https://doi.org/10.1063/1.5112898

7. A Paper entitled "Morphology, optical band gap and electrochemical studies of electrochemically synthesized Polyaniline/Cobalt oxide" **AIP Conference Proceedings.**
Ashokkumar S P, Vijeth H, Yesappa L and Devendrappa H*
https://doi.org/10.1063/5.0001659

8. A Paper entitled "Cyclic Voltammetry, Morphology and Thermal Studies of Electrochemically Synthesized PANI/CuO Nanocomposite for Supercapacitor Application" **AIP Conference Proceeding.**

Ashokkumar S P, Vijeth H, Yesappa L, Vandana M, Veeresh S, Ganesh H, Nagaraju Y S &Devendrappa H* https://doi.org/10.1063/5.0009209

9. A Paper entitled "Structure and Optical Band Gap Study of Electrochemically Synthesized Polyaniline/ZnO Nanocomposite for Energy Storage Devices" **AIP Conference Proceedings.**
Ashokkumar S P, Vijeth H, Yesappa L, Vandana M, Veeresh S, Ganesh H, Nagaraju Y S and Devendrappa H* https://doi.org/10.1063/5.0009210

10. A Paper entitled "Hybrid Core-Shell nanostructure made of Chitosan incorporated Polypyrrole Nanotubes decorated with NiO for All-Solid-State Symmetric Supercapacitor Application" in ***Electrochimica Acta. (IF 6.2)***
Vijeth H, **Ashokkumar S P,** L Yesappa, Vandana M and H Devendrappa*
https://doi.org/10.1016/j.electacta.2020.136651 0013-4686/© 2020.

11. A paper entitled "Flexible all Solid State Asymmetric Supercapacitor Based on Polythiophene Nanocomposites/Charcoal with High Energy Density" in ***RSC Advances,*** 2018, 55(8), 31414-31426.
Vijeth H, **Ashokkumar S P,** Yesappa L, Niranjana M, Vandana M, Devendrappa H*
https://doi.org/10.1039/C8RA06102E

12. A paper entitled "Camphor sulfonic acid assisted synthesis of polythiophene composite for high energy density all-solid-state symmetric supercapacitor". In ***Journal of Materials Science: Materials in Electronics,*** **(2019),** ***30*****(8),** 7471-7484.
Vijeth, H, **Ashokkumar, S P**, Yesappa, L, Niranjana, M., Vandana, M &Devendrappa, H.
https://doi.org/10.1007/s10854-019-01060-2

13. A Paper entitled "Camphor sulfonic acid surfactant assisted polythiophene nanocomposite for efficient electrochemical hydrazine sensor". In ***Material Research Express.***
Vijeth H, **Ashokkumar S P,** L Yesappa, Vandana M and H Devendrappa*
https://doi.org/10.1088/2053-1591/ab5ef5

14. A paper entitled "Chitosan Mediated Polypyrrole Nanotube Decorated with MoS_2 Quantum Dots for Solid State Supercapacitor Applications" in ***Journal of Power Sources.***
Vijeth H, **Ashokkumar S P,** Vandana M, Boukherroub, Rabah and Devendrappa H*
Submission manuscript ID : NR-ART-05-2020-004173

15. A paper entitled "Modified Thermal, Dielectric, and Electrical Conductivity of PVDF-HFP/LiClO4 Polymer Electrolyte Films by 8 MeV Electron Beam Irradiation" in ***ACS Omega***, 2018, 3(10), 14188-14200.
Yesappa Laxmayyaguddi, Niranjana Mydur, **Ashokkumar Shankar Pawar,** Vijeth Hebri, M. Vandana, Ganesh Sanjeev and Devendrappa Hundekal*
https://doi.org/10.1021/acsomega.8b01097

16. A paper titled "Optical Properties and Ionic Conductivity Studies of 8MeV Electron Beam Irradiated Poly (vinylidene fluoride-co- hexafluoropropylene)/ LiClO4 Electrolyte Film for Opto-Electronic Applications" *RSC Advances*, 2018, 8, 15297–15309. (IF 3.108).
Yesappa L, Niranjana M, **Ashokkumar S P,** Vijeth H, Basappa M, Jishnu Dwivedi, V C Petwal, Ganesh S, Devendrappa H*. doi: 10.1039/c8ra00970h

17. A paper entitled "Localized polarons in in situ synthesized polyaniline nanocomposite improve the morphology and the thermal and electrical conductivity "in ***RSC Advances,*** 2016, **6**, 115074-115084.
M. Niranjana, L. Yesappa, **S.P. Ashokkumar,** H.Vijeth, S. Raghu and H. Devendrappa.
https://doi.org/10.1039/C6RA24137A

18. A paper entitled "Investigation of the Structure, Optical and Electrical Properties of Lithium Perchlorate Doped Polyaniline Composite: Aloe Vera Used as a Bio-Plasticizer" in **Journal of Electronic Material,** 2017, 1-12. L.
Yesappa, M. Niranjana, **SP Ashokkumar,** H. Vijeth, C. Sharanappa, S Raghu, H Devendrappahttps://doi.org/10.1007/s11664-017-5724-1

19. A paper entitled "Characterization, Electrical Conductivity and Electrochemical Performance of Polyaniline-LiClO4-CuO Nanocomposite for Energy Storage Applications" in ***Polymer-Plastics Technology and Engineering (Taylor & Francis),*** 2018, 1-1.
L. Yesappa, M Niranjana, **S Ashokkumar,** H Vijeth, S Raghu, H Devendrappa
https://doi.org/10.1080/03602559.2018.1466175

20. A paper entitled "Increased porous morphology and thermal degradation of electron beam-irradiated PVDF-HFP/LiCLO4 polymer electrolyte" in ***Radiation Effects and Defects in Solids (Taylor & Francis),*** 2018, 601-607.
L Yesappa, M Niranjana, **SP Ashokkumar,** H. Vijeth, Ganesh Sanjeev, H Devendrappa
https://doi.org/10.1080/10420150.2018.1486840

21. A paper entitled "Effect of electron beam irradiation on structure, morphology, and optical properties of PVDF-HFP/PEO blend polymer electrolyte films" In ***Journal of Radioanalytical and Nuclear Chemistry 322 (1), 5-10.***
L Yesappa, **SP Ashokkumar,** H Vijeth, M Basappa, Sanjeev Ganesh, H Devendrappa
https://doi.org/10.1007/s10967-019-06466-0

22. A paper entitled "Surfactant assisted Surface Morphology and Thermal Properties of Polythiophene Composites", **AIP Conference Proceedings** 1849, 020043 (2017).
Vijeth H, Niranjana M, Yesappa L, **Ashokkumar SP,** Sharanappa Chapi, Raghu S, Devendrappa H. http://dx.doi.org/10.1063/1.4984190

23. A paper entitled "Structure, morphology and optical studies of Li+ doped polyaniline composite" AIP Conference Proceedings 1832, 040011 (2017)

L. Yesappa, M. Niranjana, **S. P. Ashokkumar,** Vijeth, Sharanappa Chapi, S. Raghu and H Devendrappahttps://doi.org/10.1063/1.4980213

Seminar/ Work shop attended /Co-Curricular activities

1. Participated in "Research methodology" workshop held at Department of Physics Mangalore University.
2. Attended National Seminar on "Inter-disciplinary Research: Challenges and Opportunities" organized by Association of British scholars Mangalore Chapter held at Mangalore University during October 18, 2016.
3. National Seminar & Workshop on Function Nanomaterials for Energy, Environment and Health organized by Mangalore University, Mangalagangotri on 21st and 22nd March 2016.
4. National workshop on Emerging Targets and Biomarkers in Cancer Therapy National Workshop on 16-18 May, 2016 at Mangalore University. National Seminar on "Inter-disciplinary Research Challenges and Opportunities" held at Mangalore University, Mangalagangothri on October 18, 2016.
5. Participated in the "Emerging Solar PV Technology Applications For Academic**"** Conducted at Mangalore University on 3rd December 2016 at Mangalore University.
6. Participated in a seminar on "Engineering Education & Research Seminar" held at The Gateway Hotel, Mangalore on February 09, 2017.
7. A Global Initiative of Academic Networks (GIAN) programme on "Nanostructure based wide band gap semiconductors for sensor applications" held at Department of Physics, Mangalore University Mangalore from 11th -17th October 2018.

Foreign visit

- Participated and presented an article entitled "Structure, Morphology, Thermal and Electrochemical Studies of Electrochemically Synthesized Polyaniline/Copper Oxide Nanocomposite for Energy Storage Devices" in the 5th edition of Nanotech France 2019International Conference and Exhibition **NANOTECH FRANCE – 2019** held at **PARIS – FRANCE** during 26-28th June 2019.

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